Electromagnetics Code Management

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LLNL's EMSolve code is a 3-D, parallel, finite element code for solving Maxwell's equations. EMSolve, which has been used in support of many LLNL programs, has modules for electrostatics, magnetostatics, eigenvalues, eddy currents, and wave propagation. The purpose of this project is to verify, document, and maintain the EMSolve suite of computational electromagnetics codes.

Project Goals

The goals for FY2007 are:

1. install EMSolve on the new Peleton machines: Yana, Zeus, Hopi, and Rhea;
2. incorporate a new linear equation solver into EMSolve;
3. set up efficiency enhancements for an important class of applications described by a tensor product mesh; and
4. collaborate with Ohio State University (OSU) on local higher-order absorbing boundary conditions (ABCs).

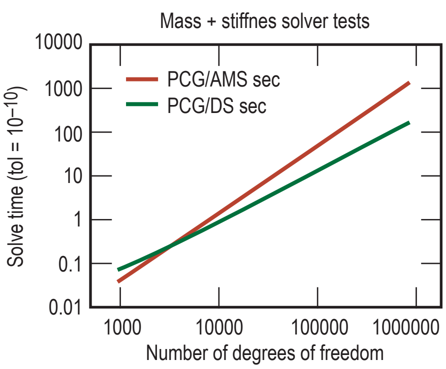

Figure 1. Improved run time of AMS solver vs. diagonally scaled preconditioned conjugate gradient (PCG). For a 1-million-unknowns problem, the AMS solver is approximately 10 times faster than the existing solver.

Relevance to LLNL Mission

EMSolve can perform electromagnetic analyses that cannot be performed by commercial codes. Having this unique computational EM capability allows LLNL to have a competitive edge. Increasing the accuracy and efficiency of our CEM codes will benefit all customers.

FY2007 Accomplishments and Results

AMS. In 2006 the HYPRE iterative solver library introduced an experimental multigrid solver called the Auxiliary Space Maxwell Solver (AMS) for linear systems involving edge elements and the corresponding CurlCurl operator. The goal of this project was to evaluate this solver's effectiveness on our class of problems and, should it prove effective, to incorporate it into the EMSolve suite.

We produced an iterative solver that is tuned specifically for edge-element discretization of curl-curl equations. The AMS is applicable to magnetostatic problems, eddy current problems, and implicit full-wave problems. The solver is based on multigrid concepts and is almost scalable, meaning that the computation time increases linearly with the problem size.

Incorporation of AMS into EMSolve was not a trivial procedure because AMS requires additional information beyond the system matrix. It also requires information about the edge-to-node connectivity of the mesh and coordinates of the individual nodes. This necessitated augmenting the generic solver interface and modifying a large number of modules that make use of this interface.

The end result is that the EMSolve suite of codes now has a new and effective multigrid solver for electromagnetic problems as well as a more useful and robust interface for all of our linear solvers (Fig. 1).

Efficiency Enhancements. We implemented a specialized simulation code that can model electromagnetic wave propagation using the scattered field formulation of Maxwell's coupled first-order field equations. This code is tuned to model blocks of materials arranged in Manhattan geometries with varying permittivity, permeability, and electrical conductivity.

This code was used to model several problems for the DARPA VisiBuilding project which endeavors to determine the location and makeup of interior walls of buildings using radar techniques. EMSolve was used to evaluate the importance of correctly modeling cinderblock voids and metal reinforcing rods within walls. Using these full-wave techniques, we were able to show that solid walls and floors produce strong wave guiding effects that are virtually destroyed by the presence of voids or rebar within those structures.

Using this new code we performed extraordinary computations (Fig. 2) on the Zeus machine. The computations consisted of a series of four simulations of a two-story building with and without cinderblock voids and metal reinforcing rods resolved to 1 cm. Each of these simulations required over 10 billion mesh elements (60 billion field unknowns) and 2.1 TB of memory.

Figure 3 shows a cut-away view of a radar pulse propagating in the two-story building. Figure 4 is a close-up of the geometry of the building.

Local ABCs. Electromagnetic radiation and scattering problems require that an ABC be applied to the boundary of the mesh. The ABC is often the

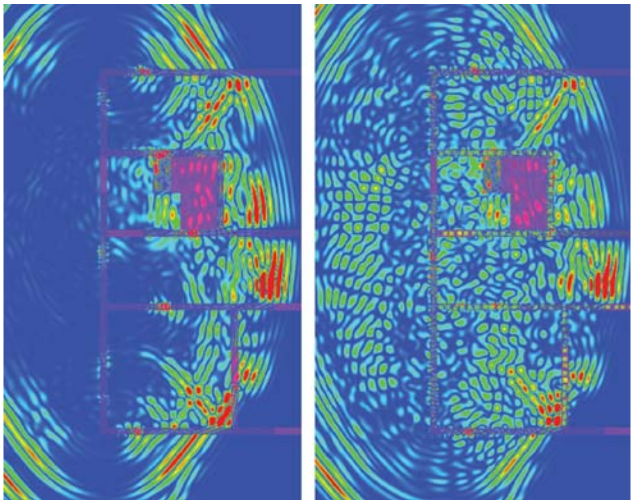

Figure 2. Comparison of radar scattering in a solid cement wall building (left) vs. a rebar reinforced cinder block building (right). Note that this is a slice through a full 3-D simulation. The color represents the magnitude of the electric field: red is maximum and blue is minimum.

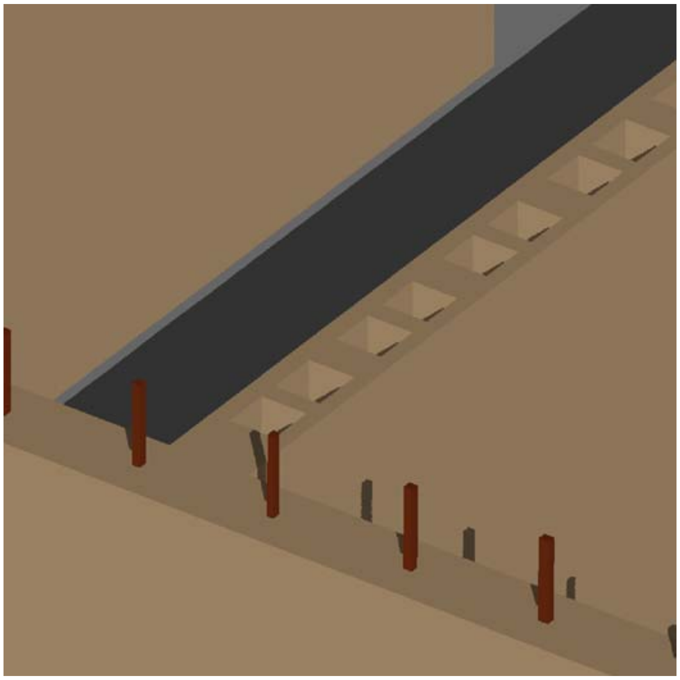

Figure 4. Close-up view of the modeling detail. Custom software was used to generate the mesh for the 10-billion-element simulations.

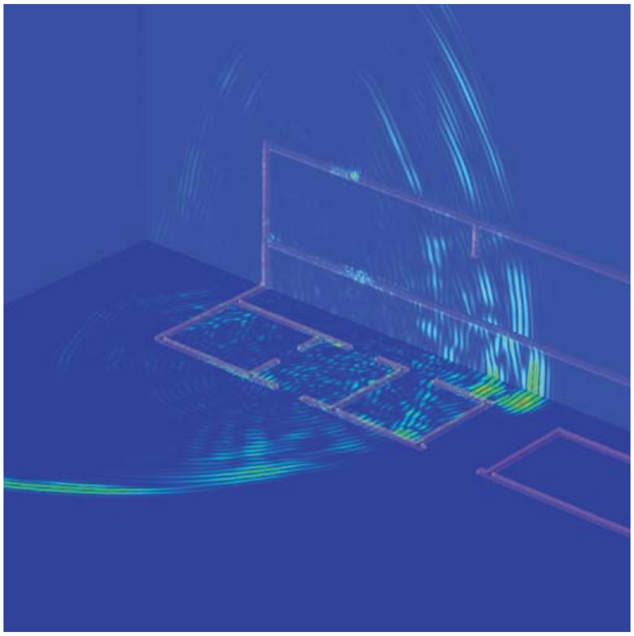

Figure 3. Cutaway snapshot of a radar pulse propagating through the building. Note how the walls themselves act as waveguides. The field propagates within the wall at a slower velocity compared to free-space.

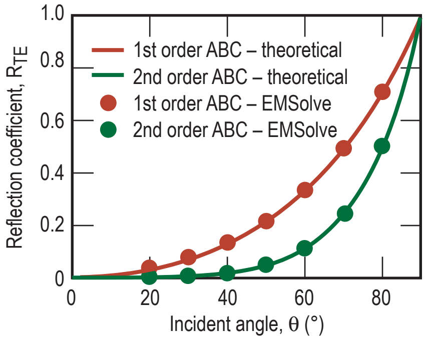

Figure 5. Verification of the second-order local ABC. The solid lines are the theoretical results; the circles represent the computed results. Note how the second-order ABC is significantly better than the first-order ABC for off-normal incidence, providing more attenuation (y-axis) over a greater range of incidence angles (x-axis).

limiting factor in achieving an accurate simulation. This task was to incorporate recent work on higher-order local ABCs into EMSolve. The term "higher-order" refers to the performance of the ABC for off-normal incidence. The term "local" means that the ABC requires only local field information, in contrast to "global" boundary conditions, which require an integral over the entire bounding surface. Figure 5 shows verification of the implementation of the second-order local ABC in EMSolve. The addition of this new capability will result in more accurate simulations with little increase in computational cost.

FY2008 Proposed Work

There are three tasks for FY2008. We will collaborate with OSU on 1) higher-order local ABCs, with the goal of constructing a time-domain version of the algorithm; and 2) an algebraic domain decomposition preconditioner for Helmholtz equations. We will also construct software infrastructure to support *hp*-refinement. The challenge is to implement the algorithm in an existing code, rather than starting from scratch. This effort will result in a simulation capability that is much more robust and easier for end-users.